ECONOMY AND ENVIRONMENT PROGRAM FOR SOUTHEAST ASIA

Controlling Automotive Air Pollution: The Case of Colombo City

Sunil Chandrasiri

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Mailing address: Tanglin PO Box 101, Singapore 912404.
Visiting address: 7th Storey RELC Building, 30 Orange Grove Road.
Tel: 65 235 1344 Fax: 65 235 1849
Internet: dglover@idrc.org.sg or hermi@laguna.net
Website: http://www.idrc.org.sg/eepsea

Comments should be sent to the author: Sunil Chandrasiri, Department of Economics, University of Colombo, Kumarathunga Munidasa Mawatha, Colombo, Sri Lanka
E-mail: econ@vidya.cmb.ac.lk

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Sunil Chandrasiri

1.0 INTRODUCTION

Increased vehicle emission in Colombo is one of the most important environmental issues that has drawn the attention of policymakers, administrators, and environmentalists in the recent past. Various studies undertaken by regulatory agencies and researchers clearly indicate that inefficient combustion of petroleum in motor vehicles is the primary cause of growing air pollution in Colombo. Lack of information on economic and environmental costs of vehicle emission and its mitigation and prevention have inhibited public response and enforcement, and impeded the implementation of existing laws, and the development of further regulations. Policy-oriented research in these areas may contribute to a better understanding of the problem and the introduction of effective control measures.

The worst prevalent air pollutants emitted from vehicles include particulate matter (PM), lead (Pb), non-methane volatile organic components (NMVOC), nitrogen oxide (NOx), sulfur dioxide (SO_2), and carbon monoxide (CO). Of these, particulate matter and lead are the most harmful components of vehicle exhaust that affect the environment and human beings. Apart from pollutants emitted by petrol-driven vehicles, the amount of exhaust from diesel-driven vehicles is large and therefore a matter of major public concern due to its undesirable environmental effects. Although diesel-engine exhaust contains less toxic gases, it has a much higher particulate matter concentration than petrol-engine exhaust. In Sri Lanka, the observed levels of TSP, SO_2, O_3, and lead are significantly higher than air quality standards recommended by the World Health Organization (WHO) and the Central Environmental Authority (CEA) in Sri Lanka. This clearly demonstrates the special nature of the vehicle emission problem in the country which is directly linked with a wide range of factors such as composition and increase in number of vehicles, price structure of fuel, lack of traffic management, use of low-quality fuel, and absence of alternative fuels.

Colombo is the main commercial and business center of Sri Lanka and as a consequence, many people are drawn into the city daily. The central district, which comprises of Fort and Pettah, provides more than 100,000 jobs and is estimated to have a daytime population of more than 650,000. The greater Colombo area contains over 4 million people or 26% of the island's population, but covers only 5.6% of the total land area. Outside the city, Katunayake International Airport and the Free Trade Zone further increase traffic congestion in Colombo. As the most important business and administrative center, Colombo attracts the highest number of vehicles and individuals and is therefore highly vulnerable to health hazards due to vehicle emissions.

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[1] The research grant and advisory assistance provided by EEPSEA in carrying out this study are gratefully acknowledged. The suggestions and advice given by Daigee Shaw at various stages of the study are gratefully appreciated. Helpful comments by Mohan Munasinghe, David Glover, Herminia Francisco, Gamini Gunasekera and Bill Barron are also appreciated. A special word of thanks goes to S. K. Cyril of CPC and P. Samarakkody of NBRO for some of the data. All remaining errors are mine.

The main objective of this study was to identify relevant policy variables and least cost methods of controlling vehicular air pollution in urban Colombo. The more specific objectives were:

a. To study the overall growth of the oil-based road transport system;

b. To identify the different air pollutants in Colombo;

c. To analyze policy variables relating to demand for petrol and diesel vehicles;

d. To estimate costs relating to various air pollution control measures; and

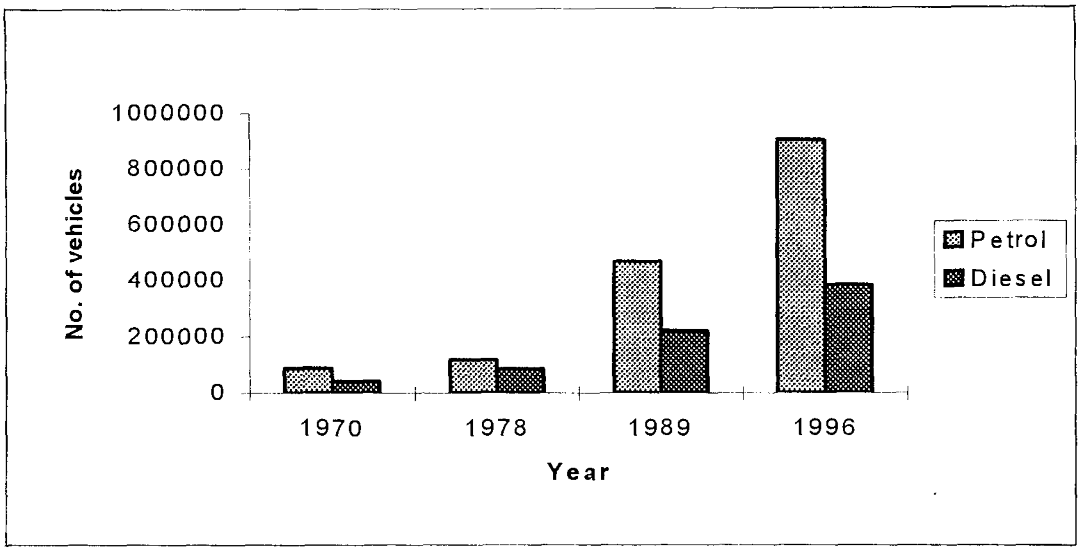
e. To recommend cost-effective strategies to improve overall air quality in Colombo and thereby reduce possible health effects.

This study is organized into five main sections: (a) the overall growth of the oil-based road transport system, (b) an inventory of ambient air pollution levels in Colombo, (c) the demand for vehicles and vehicle fuel in Sri Lanka, (d) cost-effectiveness of alternative technological measures to control automotive air pollution, and (e) an analysis of policy issues. The city of Colombo was chosen as the target area for the study because of its high rate of urbanization, high population density, relatively old and poorly maintained vehicles, and its ever increasing traffic volume.

2.0 THE OVERALL GROWTH OF THE OIL-BASED ROAD TRANSPORT SYSTEM

This section provides some background information on the oil-based road transport system in Sri Lanka. In particular, it presents information on vehicle types, increase in number of vehicles, fuel consumption, and traffic volume in Colombo.

The total number of vehicles in Sri Lanka has increased from 129,520 in 1970 to 1,374,144 in 1996, showing a significant increase over 26 years. Petrol and diesel are the main sources of fuel for road transport, and are distributed by the Ceylon Petroleum Corporation (CPC). Figure 1 shows that the increase in vehicle population in Sri Lanka was significantly higher during the post-1977 period. Of the total vehicles about 44% are active in the Colombo Metropolitan Area (CMA). The composition of fleet (all fuel types) in Sri Lanka and the changes over the last two and a half decades are shown in Table 1. The share of petrol vehicles has remained high compared with diesel vehicles. This is mainly due to the high growth of motorcycle imports during the 1980s and 1990s. For example, the relative share of motorcycles in the total vehicle number increased from 41% in 1989 to 52% in 1995. In the category of petrol vehicles, the relative share of motorcycles increased from 18% in 1970 to 23% in 1978, and from 61% to 73% in 1989 to 1996. This deserves special emphasis because of the high emission rates associated with motorcycles. Literature shows that motorcycles contribute 50% more hydrocarbons per kilometer than passenger cars and an almost equal amount of particulate matter as buses and lorries (Walsh 1992).



Source: Registrar of Motor Vehicles.

Figure 1. Increase in population of vehicles by type in Sri Lanka, 1970-96

Table 1. Vehicle types (all fuel types) in Sri Lanka (%), 1970-1996

	1970	1978	1989	1996
Petrol vehicles				
Cars	40.1	33.5	19.4	15.6
Buses	1.1	0.9	0.6	0.0
Lorries	16.6	11.8	6.0	2.7
Dual-purpose	NNR	NNR	0.5	6.3
Motorcycles	10.24	11.4	41.3	51.6
Ambulance	0.2	0.2	0.1	NG
Land vehicles	NG	NG	NG	NG
Three-wheelers	-	-	-	0.9
Diesel vehicles				
Cars	0.5	1.3	2.3	2.3
Buses	9.4	18.7	9.3	4.2
Lorries	13.3	11.2	0.2	7.8
Dual-purpose	NG	NG	1.6	7.5
Ambulance	NG	NG	NG	NG
Land vehicles	8.5	10.8	8.5	6.8
All fuel types	*100.0*	*100.0*	*100.0*	*100.0*

NG = negligible, NNR = no new registrations.
Source: Registrar of Motor Vehicles.

Table 2 shows the vehicle composition from 1970 to 1996 excluding motorcycles. In contrast to the evidence presented in Figure 1, Table 2 reveals an increasing share of diesel vehicles from 35% to 60% between 1970 and 1996.

Table 2. Vehicle types, excluding motorcycles (all fuel types), 1970-1996

	1970	1978	1989	1996
Petrol vehicles	%	%	%	%
Cars	44.6	37.9	33.0	32.2
Buses	1.2	1.0	1.1	NG
Lorries	18.4	13.4	10.1	NG
Dual-purpose	NNR	NNR	0.8	NG
Ambulance	0.2	0.2	0.1	0.1
Land vehicles	NG	0.1	NG	NG
Three-wheelers	-	-	-	1.9
Diesel vehicles				
Cars	0.6	1.4	4.0	4.8
Buses	10.4	21.1	15.8	8.7
Lorries	14.9	12.6	17.5	16.2
Dual-purpose	NG	NG	2.7	15.7
Ambulance	NG	NG	NG	NG
Land vehicles	9.6	12.2	14.5	14.1
All fuel types	*100.0*	*100.0*	*100.0*	*100.0*

NG = negligible, NNR = no new registrations.
Source: Registrar of Motor Vehicles.

Table 3 shows that all vehicle types increased during the post-1977 period. The late 70s signaled the start of an open market economy in contrast to an inward-looking, control-oriented policy regime before that. In overall terms, the growth rates of all types of vehicles decreased during the 1994-96 period with the exception of petrol cars. The analysis also revealed high growth rates in all categories of diesel vehicles. More specifically, among petrol-driven vehicles only cars and motorcycles recorded high growth rates in the mid-1990s. Among different vehicle types, diesel-driven dual-purpose vehicles posted the highest growth, whereas cars (both petrol and diesel-driven) and lorries recorded a moderate growth compared with other vehicle types. In addition, three-wheelers, especially diesel-driven ones, showed a phenomenal growth over the last 4 years. The trend also shows an imbalance in numbers between petrol and diesel-driven vehicles. Even though diesel vehicles are comparatively more expensive than petrol vehicles, the price disparity between diesel and petrol fuel has resulted in an increase in diesel vehicles, particularly cars, light vehicles, 4-wheel drives, pick-ups, and dual-purpose vehicles.

In line with these developments traffic growth in the main corridors of Colombo has also increased from 3% to 5% per annum between 1962-80 and 1981-96. Among vehicle types, cars, vans, and dual-purpose vehicles contributed more than 40% to the clogging in most roads during traffic hours. The high congestion in Colombo is not due to a road capacity problem, but to other reasons such as pricing policy of the transport sector and traffic management.[2]

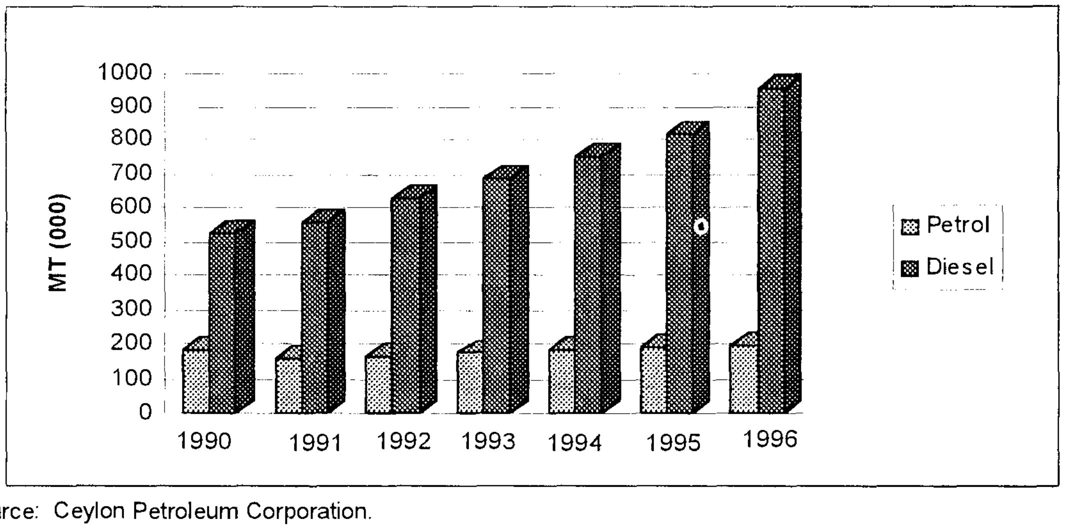
[2] For details see Jayaweera (1996).

Table 3. Increase in vehicles by fuel type

	1961-64	1965-69	1970-77	1978-88	1989-93	1994-96
Petrol Vehicles						
Cars	0.1	2.76	2.6	6.1	4.3	9.7
Buses	2.4	5.5	2.3	9.1	0.1	0
Lorries	8.9	1.7	0.6	5.3	0.1	0
Dual-purpose	NNR	NNR	NNR	33.8	7.0	0
Motorcycles	1.6	4.4	4.9	22.2	16.4	5.7
Ambulance	15.6	11.2	5.6	3.4	0.8	0
Tractors	6.3	NG	10.7	NNR	NNR	NNR
All petrol vehicles	*1.2*	*2.5*	*2.5*	*13.4*	*12.1*	*6.0*
Diesel vehicles						
Cars	4.1	39.0	12.47	17.3	10.8	6.0
Buses	27.7	10.5	15.9	5.0	3.5	2.1
Lorries	18.5	5.1	1.7	10.9	4.7	7.8
Dual-purpose	NNR	NNR	NNR	82.2	31.6	20.4
Ambulance	NNR	NNR	27.7	19.8	36.0	8.9
Tractors	27.4	22.2	6.1	9.5	5.3	6.4
All diesel vehicles	*11.0*	*13.1*	*5.0*	*11.6*	*8.9*	*5.4*

NG = negligible, NNR = no new registrations.
Source: Registrar of Motor Vehicles.

Figure 2 shows that annual consumption of vehicle diesel has grown much faster than petrol consumption. The average annual growth of petrol and diesel consumption between 1986 and 1996 is 4.3% and 6.6%, respectively. In 1997 the total consumption of leaded and unleaded petrol stood at 200,000 and 25,000 t, respectively, whereas the total diesel consumption was 1,100,000 t. Of this, locally manufactured desulfurised diesel accounted for about 500,000 t and direct imports for the remaining 600,000 t. The diesel to petrol consumption ratio has changed significantly from 1.5 in 1970 to 4.8 in 1996. The rise can be attributed mainly to the high increase in diesel vehicles and high consumption rates of vehicle diesel. The joint effect of these factors has lead to a greater increase in vehicle emissions from diesel vehicles especially in Colombo.



Source: Ceylon Petroleum Corporation.

Figure 2. Growth in fuel consumption by road users

It is thus clear that the market demand for diesel vehicles, especially cars and dual-purpose vehicles (vans), has significantly increased over the last few years. Diesel engines are substantially more fuel-efficient than equivalent petrol engines. However, emission of some pollutants, especially those affecting urban air quality tends to be higher from diesels than petrol vehicles (Faiz 1996).

3.0 INVENTORY OF AMBIENT AIR POLLUTION MEASUREMENT

This section deals with ambient air quality levels of vehicular emissions in Colombo. The assessment is based on existing studies that have been carried out during the early 1990s. The general pattern emerging from these studies points to a contamination of the city environment due to vehicle emissions.

Air quality monitoring and management in Sri Lanka has just started. The CEA, Ceylon Institute for Scientific and Industrial Research (CISIR), and the National Building Research Organization (NBRO) are currently entrusted with the task of monitoring ambient air quality levels in Colombo. The first major effort to measure air quality in the city was undertaken by the NBRO in a three-year program comprising two phases. Phase I (1989-91) was carried out to assess air quality in Colombo through determination of sulphation rate (SR) and dust fall (DF). This was a preliminary assessment based on 49 selected locations in Colombo. Findings indicated that eight locations had high average SR and DF values and all of them were located near traffic intersections or industrial areas.[3] Of 49 locations 14 had average SR values of <0.1 mg/100 cm^2/day, 28 locations had average SR values ranging from 0.1 to 0.19 mg/100 cm^2/day, and 7 locations had average SR values >0.2 mg/100 cm^2/day. For DF, of the 49 locations, 15 had average DF values <200 mg/m^2/day, 12 locations had average DF values in the range of 200-300 mg/m^2/day, and 12 locations had >300 mg/m^2/day. The air quality of these critical locations was monitored to measure suspended particulate matter (SPM), lead, CO, SO_2, and NO_2 during Phase II (1992-93) of the program.

Table 4. Status of air pollution due to vehicle emissions in Colombo

Pollutant	Grand mean concentration	Range
TSP	404 μg/m^3 (g h)	100-700 μg/m^3 (g h)
Pb	0.415 μg/m^3 (g h)	0.01-2.0 μg/m^3 (g h)
CO	4.0 ppm (3 hr)	2.25 ppm
SO_2	0.019 ppm (3 hr)	0.0045-0.054 ppm
THC	2.7 ppm (3 hr)	2-5 ppm
NMHC	0.83 ppm (3 hr)	0.2-3.00 ppm
CH_4	1.9 ppm (3 hr)	1.8-2 ppm

Source: Mathes et al. (1993).

The CEA also carried out an air quality monitoring program in 1991-92 to measure levels of THC, CO, NO_2, and SO_2 in Colombo. Results showed that NO_2 concentration in the Colombo Metropolitan Area is way above the safety levels, whereas CO concentration is below the minimum level even during peak traffic hours.

[3] For details see NBRO (1993).

Mathes et al. (1993) carried out a study on ambient air quality levels under dry weather conditions using sample observations selected from major traffic junctions in Colombo. Based on survey data Mathes et al. (1993) established a high correlation between TSP levels and traffic density in Colombo. For example, the traffic volume along major roads such as Maradana Road, Reid Avenue, Galle Road, and Lotus Road constitute about 41,770, 38,800, 37,7000, and 34,650 vehicles, respectively, during a 12-h period in a day. The related pollutant concentrations under such traffic conditions are summarized in Table 4. The study also revealed that observed TSP and NMHC exceeded required levels of WHO (150-230 μg) and USEPA (0.24 ppm /3 hr).

Arewgoda (1994) also conducted a study in the CMA using blood samples collected by venipuncture from different target groups, i.e., street vendors, school children, three-wheeler drivers, motorcycle riders, and traffic policemen. Results are summarized in Table 5. Findings gave clear evidence of significantly higher lead levels in blood in some members of the test population who are exposed to vehicle emissions than the control group. Traffic policemen were the worst affected. More recent data (Annex 1) revealed that current air pollution levels in Colombo exceeded recommended values for Sri Lanka.

Table 5. Average lead levels in blood and confidence limits

Subject group	Pb in blood in μg/dL		
	Mean	Std. error	Conf. interval
School children (4 and 5 years old)	5	0.40	5.07 + 0.82
Motorcycle riders	12	1.17	11.97 + 2.55
Street vendors	13	1.07	12.59 + 2.20
Three-wheel drivers	15	1.16	15.12 + 2.49
Traffic police	53	1.61	53.07 + 2.38
Control for the adult group	9	0.65	8.77 + 1.34

Source: Arewgoda (1994).

Table 6. Estimated emission from petroleum combustion sources

Sources		SPM	SO_2	NOx	HC	CO
Transport	t/year	3,453.0	455.0	5,928.0	38,364	19,9736.0
	%	88.2	4.3	81.6	99.78	99.9
Industry	t/year	358.4	9,791.2	1,243.6	68.59	98.0
	%	9.2	93.5	17.1	< 1	< 1
Power & commercial	t/year	1.6	107.4	20.4	0.19	1.2
	%	< 1	< 1	< 1	< 1	< 1
Households	t/year	100.5	113.4	76.7	13.34	8.337
	%	2.5	< 1	< 1	< 1	< 1
Total	t/year	3,913	10,467	7,268	38,446	199, 843

Source: MEIP (1992).

In addition to these studies an emission inventory prepared by the Metropolitan Environment Implementation Programme (MEIP) also indicated the relative significance of the transport sector as a source of air pollution in urban Colombo (Table 6). The inventory covers major air pollutants such as SPM, SO_2, NOx, CO, and hydrocarbons.[4] It is clear that the transport sector is the biggest contributor to air pollution in Colombo and emissions from other sectors are fairly low, except for SO_2, with the industrial sector accounting for nearly 93% of total emissions. Work by Fernando and Tennakoon (1996) further confirms the relative significance of the transport sector as a source of air pollution.

It is thus clear that in Colombo pollution levels due to vehicle emissions are significantly higher than the minimum levels recommended by WHO and CEA in Sri Lanka.[5] Given the high increase in vehicles, high proportion of old vehicles, absence of clean fuel, poor vehicle maintenance and traffic management, high rate of urbanization, and slow growth of road networks, there is every possibility that ambient air quality levels in Colombo may further deteriorate and as a result externality costs associated with vehicle emissions may continue to go up.

4.0 DEMAND FOR VEHICLES AND VEHICLE FUEL

This section discusses the determinants of vehicle ownership and vehicle fuel consumption in Sri Lanka. It examines the effect of vehicle fuel price on the demand for vehicles and vehicle fuel consumption. Existing work on the demand for vehicles can be summarized into two broad groups: (a) macro-level studies and (b) micro-level studies.[6] Most of these studies, however, are case-specific and their general applicability is very low especially in the context of less developed economies. Existing evidence, however, confirms the significance of fuel prices and income as key determinants of vehicle ownership even though the reported evidence is contradictory.

Vehicle demand in Sri Lanka is met by imports from various foreign sources. Of the total vehicle number, about 25% was new; the rest were reconditioned vehicles. Like in most other countries, vehicle imports in Sri Lanka are subject to various taxes and import duties, i.e., import duty, turnover tax, excise duty, cess, and defense levy. Import duties and other payments on vehicles vary quite significantly across vehicle types depending on engine capacity, fuel type, luxury status, CIF value, and vehicle status.[7] In addition, the permit scheme introduced in 1993 allowed certain user groups such as public servants, professionals, and politicians to import vehicles at concessional tax rates.[8] However, the effect of import duties and other taxes on vehicle ownership is difficult to assess at the aggregate level mainly due to paucity of data.

[4] For details on methodology, see MEIP (1992).

[5] Refers to the National Environmental (Ambient Air Quality) Regulations, 1994.

[6] For a survey of existing work on the demand for vehicles see Button et al. (1993) and references cited therein.

[7] Refers to whether brand new or reconditioned vehicles. With respect to the latter the limit is 3 years for petrol and diesel cars and 5 years for dual-purpose vehicles.

[8] Accordingly, permit holders are required to pay only 25% of the total tax levied on petrol and diesel-driven vehicles. This scheme was terminated in 1994 and was reintroduced in 1998 with the new tax rates fixed at 25% and 40% for petrol and diesel cars, respectively.

The aggregate work on the demand for vehicles tends to use relatively simple model specifications mainly due to data constraints (Button et al. 1993). Based on existing theoretical and empirical evidence we hypothesized that vehicle prices, fuel prices, and user charges are key determinants of vehicle ownership.[9] The linearized version of this functional relationship is explained in the following equations, which cover six major categories of vehicles: petrol cars, diesel cars, lorries, buses, dual-purpose vehicles, and motorcycles.

PCAROWlog	= a1 +b1PPIlog+ b2PPCARlog +b3USClog+ u	(1)
DCAROWlog	= a1 +b1DPIlog+ b2PDCARlog + b3USClog + u	(2)
DBUSOWlog	= a1 + b1DPIlog+ b2PBUSlog + b3USClog + u	(3)
DLORYOWlog	= a1 +b1DPIlog+ b2PLORYlog + b3USClog + u	(4)
DPVOWlog	= a1 +b1DPIlog+ b2PDVPlog + b3USClog + u	(5)
MCOWlog	= a1 +b1PPIlog+ b2PMClog + b3USClog + u	(6)

where:

PCAROW	= ownership of petrol cars[10] (total no. of petrol cars/total adult population)
DCAROW	= ownership of diesel cars[11] (total no. of diesel cars/total adult population)
DBUSOW	= ownership of diesel buses [12] (total no. of diesel buses/total adult population)
DLORYOW	= ownership of diesel lorries[13] (total no. of diesel lorries/total adult population)
DPVOW	= ownership of dual purpose (D/P) vehicles[14] (total no. of D/P vehicles/total adult population)
MCOW	= ownership of motorcycles[15] (total no. of motorcycles/total adult population)
PPI	= petrol price index (price of petrol/consumer price index for fuel and electricity)
DPI	= diesel price index (price of petrol/consumer price index for fuel and electricity)
PPCAR	= price of petrol cars
PDCAR	= price of diesel cars
PBUS	= price of diesel buses
PLORY	= price of diesel lorries
PDP	= price of dual-purpose (diesel) vehicles
PMC	= price of motorcycles
USC	= user charges (i.e., annual license fees)
u	= random error term.

[9] Some other models, especially in micro level studies, have identified a wide range of other factors as determinants of the demand for vehicles, i.e., vehicle safety, net horsepower, perceived quality, etc.

[10] All petrol-driven four-wheel covered vehicles up to station wagons, but not including pickups, jeeps and vans.

[11] All diesel-driven four-wheel covered vehicles up to station wagons, but not including pickups, jeeps and vans.

[12] All diesel-driven vehicles designed for the carriage of passengers, larger in size than a dual-purpose vehicle.

[13] All diesel-driven lorries larger than a dual-purpose vehicle.

[14] Diesel-driven four-wheel pickups, jeeps, and vans that can seat up to 15 persons.

[15] All motorcycles including Challys.

The data set covers a period of 37 years (1960-1997) and estimates are based on Ordinary Least Squares (OLS) method (Table 7). As expected, the coefficient of fuel price is negative and significant in all equations except for dual-purpose vehicles. This may be due to specific ownership characteristics of dual-purpose vehicles in Sri Lanka. These vehicles are owned by individuals or organizations who take full advantage of price distortions in the market. The large price differential between petrol and diesel fuel has encouraged them to invest more in diesel vehicles. Our data set for dual-purpose vehicles covers only a period of 21 years because this category was introduced only in 1976. In our estimates, the coefficient of vehicle price is significant only for petrol cars and diesel-driven lorries. The problem with other categories of vehicles may be partly due to poor data quality used in compiling price indices and partly due to distortionary effects caused by policy failures. For example, broad categories of vehicles covered in this study represent wide variations in tax rates and price levels according to engine capacity, year of manufacture and luxury status. The Sri Lanka Customs, however, does not maintain detailed records on these aspects and therefore it is difficult to compile accurate price indices for these vehicle categories. Market distortions due to policy failures refer to duty concessions extended to certain user group categories which own diesel cars and dual purpose vehicles and special privileges given to state monopolies such as the Sri Lanka Transport Board (SLTB).[16] The coefficient of user charges is negative but statistically insignificant in all equations except for petrol cars and diesel buses. This is in line with the existing policy of charging relatively low user charges (i.e., annual license fees) for petrol cars and SLTB buses.

Table 7. Determinants of vehicle ownership (Ordinary Least Squares estimates)

Vehicle ownership	Constant	Fuel price	Vehicle price	User charges	R^2
PCAROW =	+8.38	-.933PP	-.963 PPCAR	.719 USC	.711
	(7.18)[a]	(1.46)	(2.20)	(5.165)	
DCAROW =	-1.48	-.236 DP	1.14PDCAR	-.532USC	.952
	(2.49)	(1.28)	(4.26)	(.981)	
DBUSOW =	5.17	-.182 DP	+.146 PBUS	.188 USC	.972
	(17.67)	(3.34)	(2.83)	(1.92)	
DLORYOW =	5.14	-.213 DP	-.300 PLORY	.032USC	.968
	(18.49)	(2.97)	(2.28)	(.220)	
DPOW =	-2.31	1.05DP	.401PDP	-2.14USC	.845
	(1.52)	(1.10)	(4.01)	(1.74)	
MCOW =	.218	-.611 PP	-.162PMC	-.145USC	.947
	(1.08)	(1.38)	(7.23)	(.351)	

[a] Figures in parentheses are t-statistics.

[16] Refers to a public enterprise which functioned as a state monopoly up to the late 1970s. Even now, its market share is relatively large and it enjoys various tax concessions on import of buses, spare parts, and payment of user charges.

The effect of fuel price on vehicle fuel demand was also examined to assess the substitution effect between petrol and diesel consumption. This important aspect needs to be addressed because of the significant increase in diesel-driven vehicles and diesel consumption since the mid-1990s. In addition to the high import of diesel vehicles, many petrol vehicle owners (cars and dual-purpose vehicles) have replaced their vehicles with diesel engines over the last few years. In this assessment we hypothesized that income (INCM) and fuel price (price of diesel, PD and price of petrol, PP) are key determinants of vehicle fuel consumption. The linearized version of the functional relationship is explained in equations 7 and 8. Estimates were based on the Seemingly Unrelated Regression Estimates (SURE) method which is more efficient in estimating dynamic demand systems.

$$DPlog = a_1 + b_1INCMlog + b_2PPIlog + b_3DPIlog + u \quad (7)$$
$$DDlog = a_1 + b_1INCMlog + b_2PPIlog + b_3DPIlog + u \quad (8)$$

where:

DP = demand for petrol (petrol sales/ total no. of petrol vehicles)
DD = demand for vehicle diesel (diesel sales/total no. of diesel vehicles)
INCM = income (GDP per capita at constant prices).

Table 8 shows that income variable is positive and significant in both equations. In the demand function for petrol (Equation 7), the coefficient of PP is negative and significant. In the same equation, the coefficient of PD is positive and significant. In the demand function for vehicle diesel, the PP and DP coefficients are significant. These findings are in line with existing statistical evidence. For example, Ranasinghe (1989) came up with elasticity values of -0.508 and -0.034 for petrol and diesel prices, respectively. Estimates by Samaraweera produced elasticity values of -0.387 for petrol and -0.026 for diesel.[17] Work by De Silva (1989) revealed price elasticity values of -0.55 and -1.21 for petrol and diesel[18] vehicles, respectively. However, it is important to note that our study deviates significantly from these studies in both time coverage and methodology.[19] For example, the other studies cover a 15-year period from 1970 to 1985 and therefore do not capture major changes in the road transport sector during the post liberalization period. Statistical evidence on the demand analysis reveals low demand elasticities for vehicle fuel. The effect of fuel in controlling vehicular emissions will be examined later in this paper.

Table 8. Determinants of vehicle fuel demand (SURE estimates)

Type of fuel	Constant	Income	Petrol prices	Diesel price	R^2
PD	+1.76	+.296 INCM	- .078 PPI	+.250 DPI	0.67
	(9.71)[a]	(6.78)	(1.49)	(5.23)	
DD	+1.83	+.129 INCM	+ .105 PPI	- .136 DPI	0.88
	(8.80)	(2.58)	(1.75)	(2.48)	

[a] Figures in parentheses are t-statistics.

[17] It should be noted that the coefficients for vehicle diesel were not statistically significant in both studies, i.e., Ranasinghe (1989) and Samaraweera (1989).

[18] Refers to diesel consumption by passenger vehicles excluding Sri Lanka Transport Board vehicles.

[19] Estimates by Samaraweera and de Silva are based on simulation models.

5.0 COST-EFFECTIVENESS OF ALTERNATIVE TECHNICAL MEASURES

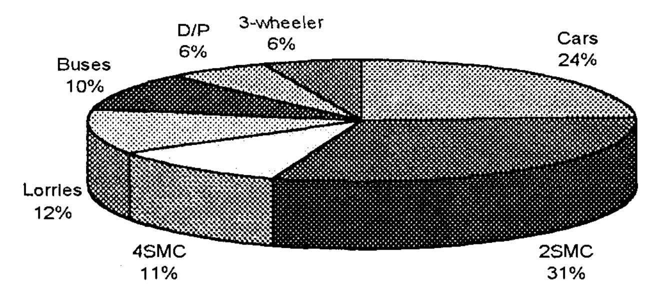
5.1 Estimated Load of Air Pollutants in Colombo

This section discusses the cost-effectiveness of selected direct measures or technical options in controlling vehicle emissions in Colombo. The purpose is to generate an ordering of potential control measures by cost to identify the most economically efficient measures for policymaking. The policy implications of both technical and nontechnical measures will be discussed in the next section. As the first step, an emission inventory was prepared for Colombo using the formula given below (OECD 1995). The emission factors and the vehicle number[20] used for this purpose are given in Annex 2.

$$\text{Emission} = \sum (\text{EFabc} \times \text{Activity abc})$$

where: EF = emission factor
Activity = amount of energy consumed or distance traveled for a given mobile source activity
a = fuel type (petrol, diesel, etc.)
b = vehicle type (car, truck, etc.)
c = emission control

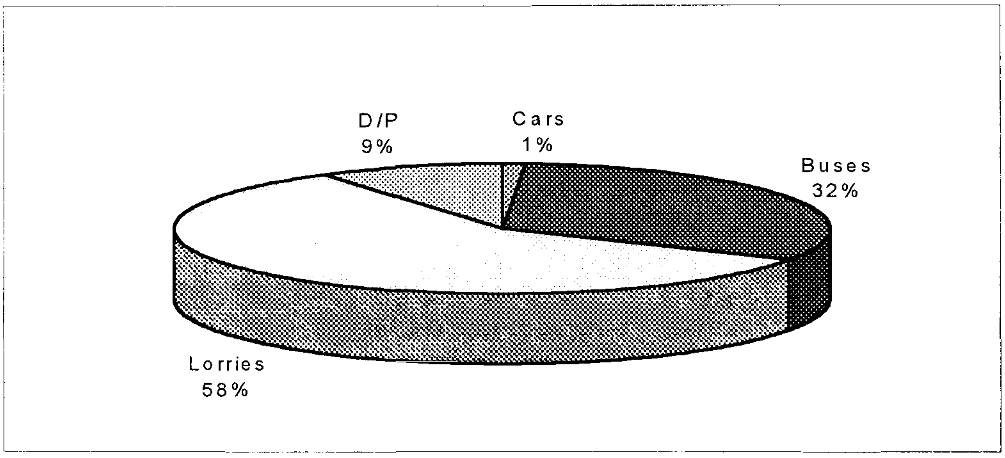
The estimates given in Annex 3 can be treated as a reasonable overall representation of vehicle emission levels in Colombo. In fact, actual emission rates could be much higher than these estimates because vehicles in Colombo are old and often operate in stop-and-go modes. Moreover, it is quite probable that estimated emission levels will be exceeded by a large margin given the rapid rate of motorization, increasing urbanization, slow growth of road network, poor maintenance of vehicles and roads, and lack of proper traffic management. Petrol and diesel vehicles account for 78% and 22% of total emissions, respectively. Figure 3 shows that among petrol-driven vehicles, cars and two-stroke motorcycles (2SMC) account for about 55% of vehicle emissions among petrol-driven vehicles, whereas buses and lorries account for about 90% of emissions among diesel-driven vehicles (Figure 4).



Source: Annex 3.

Figure 3. Emissions of petrol vehicles in Colombo

[20] In the absence of an inventory of vehicle composition the number of operational vehicles in Sri Lanka was estimated. The estimates of vehicle numbers prepared by Kumarage (1997) appear to be more accurate because they take into account both annual licensing of vehicles and survival rates for different types of vehicles.



Source: Annex 5.

Figure 4. Emissions of diesel vehicles in Colombo

Having established an emissions inventory, the next step was to assess the cost-effectiveness of various technical measures in controlling vehicular emissions in Colombo. This was attempted in the following section of the study paying particular attention to eight different technical options under two broad, direct-control strategies: introduction of "clean fuel" and "clean car."

5.2 "Clean Fuel" -- Unleaded Petrol, Desulfurised Diesel, and LPG

Fuel quality is one of the most important factors affecting vehicle emissions in Colombo. The Ceylon Petroleum Corporation (CPC), the sole supplier of vehicle fuel in Sri Lanka, imports 65% of super diesel and 100% of unleaded petrol. In addition, 35% of normal diesel and 100% of leaded petrol sold in the market are produced by CPC using imported crude oil. However, vehicle diesel produced in Sri Lanka contains about 0.8% of sulfur; as a result sulfur dioxide emissions from diesel vehicles are relatively high. The diesel produced by CPC also contains a large quantity of "high ends," which results in greater emission of hydrocarbons. In producing petrol, CPC adds terra ethyl lead at the rate of 0.24 g/L to increase the octane number of petrol. Lead petrol emits a high quantity of pollutants, especially carbon monoxide and hydrocarbons. Emissions could be reduced by improving the quality of locally produced petrol, further refining of crude oil, and addition of other less harmful additives. Unleaded petrol can extend spark plug life and increase the interval between oil changes in addition to cost savings in the long run.[21] It can also reduce lead use by 50% per annum.[22] From a production point of view this involves an additional operational cost of Rs.4/Rs.317.3 million per annum.[23]

[21] These benefits have been estimated at Canadian $ 0.24 cents/L for 16,000-km yearly driving (1980 prices).

[22] Based on the assumption that vehicle number in Colombo accounts for about 30% of petrol consumption in Sri Lanka.

[23] According to the CPC, introduction of unleaded petrol and desulfurised diesel may result in 50% reduction in lead and sulfur dioxide.

In Sri Lanka, sulfur content of diesel is around 0.8%. This level is quite high, contributing to environmental degradation both directly and indirectly and to negative health effects. Developed countries have already taken steps to reduce the sulfur content in diesel to 0.05%.[24] This is an attractive pollution control measure because the cost involved in reducing sulfur content of diesel to 0.05% is less than one U.S. cent per liter. In Sri Lanka, this cost was estimated to be around 20 cents/liter[25] or Rs.221.32 million per annum.[26] In addition, it also involves an initial capital investment of about Rs. 350 million. In terms of benefits, this may result in a 50% reduction equivalent to 3,115 t of sulfur dioxide per annum.

5.2.1 Use of liquefied petroleum gas (LPG)

LPG is typically a mixture of several gases in varying proportions and is at present the most widespread gaseous fuel. However, LPG is not commonly used in dual-fuel diesel applications due to its relatively poor knock resistance.[27] Thus, almost all LPG vehicles currently in operation are petrol vehicles. In terms of emission, LPG produces moderate HC, very little CO, and near-zero particulate emissions when used in spark ignition engine systems. It also gives longer life to lubricating oil as well as the engine because there are no carbon deposits. Moreover, gas combusts completely and does not cause erosion. The cost of conversion from petrol to a dual system varies from US$ 800 to US$ 1,500 for a light duty vehicle. In Sri Lanka, it is about Rs. 45,000 to Rs. 55,000[28] and the cost of a liter of LPG is Rs.22 as against Rs.50 per liter of petrol.

Table 9 shows the possible reductions in vehicular emissions due to the use of LPG by petrol car owners. From these estimates it is clear that the use of LPG by 30% of petrol cars would reduce emissions levels by 81% or 7,687 t per annum. These benefits would go up to 15,372 t per annum if the usage rate is increased to 60% by petrol cars in Colombo.

Table 9. Expected reductions in emission levels due to LPG (t)

% of petrol cars using LPG	Emissions due to use of petrol	Emissions due to use of LPG	Expected emission reductions
30%	9,506	1,819	7,687
40%	12,674	2,426	10,248
50%	15,843	3,032	12,811
60%	19,012	3,639	15,372

Sources of basic data: Annexes 3 and 4.

[24] For details see Faiz et al. (1996).
[25] Based on estimates prepared by the CPC.
[26] Based on 1996 vehicle diesel consumption.
[27] For details see Faiz et al. (1996) and references cited therein.
[28] Based on survey data collected from some of the leading vehicle gas suppliers in Colombo.

5.3 "Clean Car" -- Catalytic Converters

Catalytic converters, generally known as exhaust after going through treatment devices, are one of the most effective emission control devices currently available. They process exhaust using in-cylinder techniques to remove pollutants, and achieve considerably lower emissions. They require unleaded fuel because leaded petrol can significantly degrade catalyst efficiency. Hence, the cost of supplying unleaded petrol needs to be accounted as a cost element in evaluating cost-effectiveness of catalytic converters. The cost of a catalytic converter and its accompanying equipment is around US$ 450[29] or Rs.27,000. For new vehicles, however, this is not an additional cost element because the catalytic converter has become a standard requirement for new cars. In this study, the effect of catalytic converters was assessed considering new imports and existing composition of vehicles in Colombo. Accordingly, estimated emission reductions varied from 1,222 to 10,088 t/annum depending on different usage rates (Table 10).

Table 10. Expected emission reductions due to catalytic converters (CCs)

Percentage of petrol cars using catalytic converters (CCs)	Emissions due to use of petrol (t)	Emissions due to use of CCs (t)	Expected emission reductions (t)	Rate of reduction %
New imports of petrol cars (Im)	1,329	107	1,222	92
Im + 10% of current fleet	4,498	320	4,178	93
Im + 20% of current fleet	7,666	534	7,132	93
Im + 30% of current fleet	10,834	747	10,088	93

Sources of basic data: Annexes 3 and 4.

5.4 Phasing Out 2S motorcycles (2SMCs)

Two-stroke motorcycles (2SMCs) are quite popular among lower middle income earners in Sri Lanka. In relative terms, 2SMCs account for the biggest group of vehicles in the country. These 2SMCs are 20% to 25% less efficient than 4SMCs and contribute 10 times more air pollution than 4SMCs. The situation is much worse with three-wheelers because these are powered with two-stroke engines and have low fuel economy.

Our estimates show that 2SMCs account for about 42,108 t of emissions or 31% of total emissions by petrol vehicles in Colombo. If the import of 2SMCs is prohibited, emissions may be reduced by 2,418 t per annum.[30] The private cost to be borne by vehicle owners in this regard is about Rs. 51.5 million per year. This is based on the assumption that the additional cost involved in buying a four-stroke motorcycle is about US$ 100 or Rs. 6000 per unit[31].

[29] Faiz et al. (1996).

[30] This is based on the assumption that 44% of the total imports of 2SMCs (9815) is added to the total vehicle count in Colombo on an annual basis.

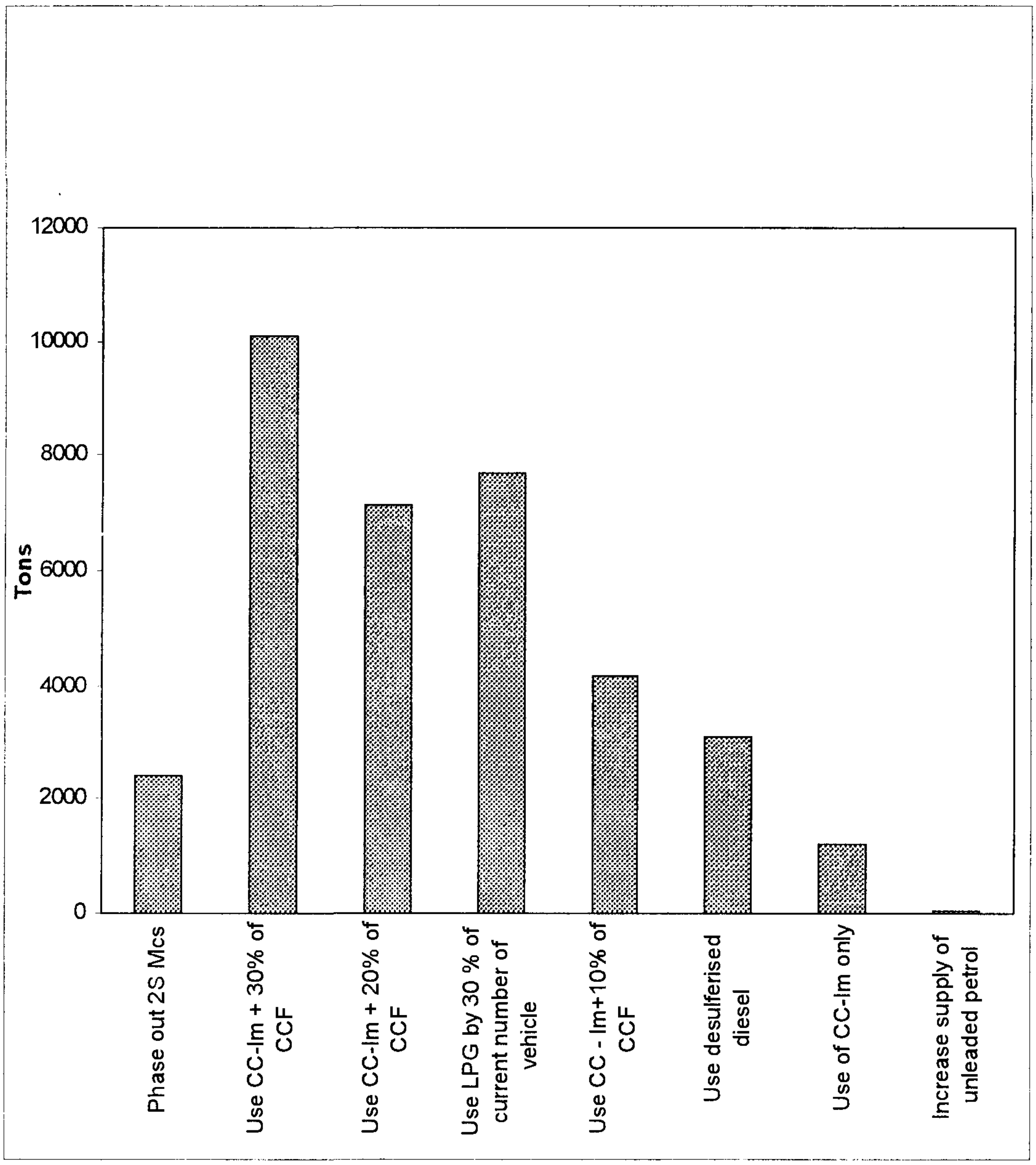
[31] Based on current market prices. See also Faiz et al. (1996).

The results of a cost-effectiveness analysis are presented in Table 11. Accordingly, the use of catalytic converters with unleaded petrol and the introduction of LPG seem to offer the highest level of emission reductions in Colombo (Figure 5). The use of desulfurised diesel also appears to be an attractive option in reducing vehicle emissions. However, in cost-effectiveness, restrictions on the import of 2SMCs may be the most cost-effective option, followed by the use of catalytic converters with unleaded petrol, and introduction of LPG and supply of desulfurised diesel. Various policy options related to these will be analyzed in the next section.

Table 11. Cost-effectiveness of various vehicle emission control strategies

Strategy	Estd. emission reductions (t)	Cost (Rs. Million)	Cost per ton (Rs. Million)
1. Phase out 2S motorcycles by prohibiting their imports	2,418	51.5	0.021
2. Unleaded petrol and catalytic converters - new imports & 30% of current vehicle composition	10,088	742.3	0.073
3. Unleaded petrol and catalytic converters - new imports & 20% of current vehicle composition	7,132	600.6	0.084
4. Use of LPG by 30% of cars - current vehicle composition	7,687	708.2	0.092
5. Unleaded petrol and catalytic converters - new imports & 10% of current vehicle composition	4,178	458.9	0.11
6. Supply of desulfurised diesel	3,115	571.32	0.183
7. Catalytic converters - new imports of cars	4,178	317.3	0.26
8. Supply of unleaded petrol	31	317.3	10.238

Note: Calculations were based on information given in Annexes 3 and 4 and facts given in section 5 of the paper. Cost figures used for catalytic converters and conversion of petrol vehicles to LPG were Rs. 27,000/= and Rs. 45,000, respectively.



Source: Annex 3.

Figure 5. Emission reductions due to various technical options

6.0 ANALYSIS OF POLICY ISSUES

This section deals with the policy environment of the road transport sector and its effects on vehicular emissions. Existing policies on vehicle imports and fuel pricing are mainly influenced by welfare and equity considerations rather than efficiency or environmental issues. The pricing policy of vehicle diesel is based mainly on welfare considerations such as provision of public transport and transport of goods at low cost. Similarly, high taxes on petrol fuel and petrol cars are based on equity rather than efficiency considerations. Existing user charges (i.e., revenue license fees) are not based on total economic costs associated with the use of petrol and diesel vehicles. In general, user charges for petrol vehicles are 50% less than that of diesel-driven vehicles. Among diesel vehicles, charges are much higher for privately owned vehicles than for a fleet owned by public sector organizations. The continued implementation of such policies over the last two and half decades has led to a highly distorted price structure in the vehicle-fuel market in Sri Lanka. For example, in the mid-1970s, vehicle diesel price was only Rs.2.09 cheaper than regular petrol. By the end of September 1989 and in 1993, this difference went up to Rs.10.40 and Rs.22.80, respectively. At present, a liter of petrol is four times more expensive than a liter of vehicle diesel.

Sri Lanka is the only country with such a big disparity between petrol and diesel prices.[32] Table 12 shows that the production cost difference between a liter of petrol and diesel is only 35 cents. In terms of selling price, however, a liter of petrol costs Rs.36.80 higher than diesel. This means that users of diesel are heavily favored as against petrol users. In addition, tax concessions have also been granted for diesel-driven buses, lorries, and vans. For example, import duties on petrol-driven vehicles are about 75% to 100%, whereas for diesel-driven vehicles duties range from 20% to 30%.

Low import duties on diesel-driven vehicles have been justified on social welfare grounds because they are usualy linked to social sectors such as passenger and goods transport. For reconditioned vehicles, restrictions applicable to petrol and diesel-driven vehicles[33] are 3 and 5 years, respectively. As a result, reconditioned diesel vehicles have become much cheaper than reconditioned petrol vehicles. In addition, the existing price and tax system does not send the right signal to users who use substitute diesel for petrol for personal use under the current system of user charges. These tax systems have completely ignored the environmental costs associated with heavy consumption of vehicle diesel. The net effect of all these policy changes has been the imbalance in growth of petrol and diesel vehicles in Sri Lanka.

It is clear that the government policy on import duties and prices for vehicle fuel has been more favorable towards diesel vehicles. As a result, privately owned diesel vehicles have significantly increased in the 1990s. For example, dual-purpose vehicles (i.e., vans and pickups) have the highest growth rate averaging about 30% per annum over the last few years. Most of these vehicles are owned by individuals in the high-income segment of the population and are used mainly for private purposes. This is an interesting example of an inefficient allocation of resources due to policy failures.

[32] For details see Faiz et al. (1996) and references cited therein.

[33] In February 1998, the government decided to allow imports of diesel-driven buses and trucks up to 10 years old.

Recent efforts to correct policies through differential tax rates such as the new diesel tax on privately owned diesel vehicles[34] have created further distortions in the market rather than improving the existing situation.

Table 12. Price structure of petrol and diesel (Rs./L), 1996

	Petrol	Diesel
Landed cost	6.63	6.58
Customs duty (35%)	3.57	3.54
Manufacturing and administration O/H	1.34	1.31
Distribution margin	0.48	0.23
Financial charges	0.31	0.32
Cost of production	**12.33**	**11.98**
Tax payments[a]	37.67	1.22
Market price	**50.00**	**13.20**

[a] Refers to turnover tax, security levy, and excise tax.
Source: Ceylon Petroleum Corporation.

Emission reduction can be realized by a combination of measures that make the polluting activity cleaner or that reduces its scale. The selection of instruments, however, depends on the elasticity of demand for the polluting good and the cost-effectiveness of various pollution control strategies. For example, emissions reduction can be achieved mostly by technical controls if the cost per unit of emission reduction and the demand elasticities are low. By contrast, emission reduction can be attained mostly by demand reductions if demand elasticities are high and control effectiveness is low. This does not mean, however, that pollution control measures are restricted only to demand management instruments or technical control measures. A combination of both instruments with due emphasis on the more important one may lead to better control measures. The effectiveness of technical measures can be complemented and refined with the application of demand management instruments.[35] For example, a fuel tax may reduce the fuel consumption by changing the behavioral pattern of vehicle owners. Moreover, demand management measures are more flexible and easy to implement. The principal weakness of such demand management measures is that it ignores differences in emission rates across different types of vehicles.

As noted earlier, the evidence on demand responses suggests that the impact of fuel price changes on vehicle fuel consumption is quite low. For example, a 10% increase in petrol price may reduce the demand for petrol by 0.78% (Equation 7). It may also increase the demand for diesel by 2.5%. For diesel a 10% price increase may reduce the demand for diesel by 1.4%. In terms of different categories of vehicles, however, the effect of fuel price on vehicle ownership varies quite significantly. For example, a 10% increase in petrol prices may reduce the demand for petrol cars and motorcycles by 9% and 6%, respectively. Similarly, a 10% increase in diesel prices may reduce the demand for diesel cars, buses, and lorries by 2.4%, 1.8%, and 2.1%, respectively. The effect of these changes in emission reduction can be summarized as: petrol cars, 2.2 t; diesel cars, 0.02 t; diesel buses, 0.6 t; diesel lorries, 1.2 t; 2SMCs, 1.9 t; and 4SMCs, 0.7 t. The expected emission reduction appears quite significant for petrol cars, diesel lorries, and 2S motorcycles.

[34] Refers to Diesel and Luxury Tax imposed beginning in September 1995. The rates are Rs.10,000 for diesel cars and vans of less than 2,200 cc; a tax of Rs. 5,000 for diesel vans for school and passenger transport; and a tax of Rs. 50,000 (reduced by Rs.10,000 each year) for diesel vehicles less than 2700 cc and petrol vehicles less than 2500 cc.

[35] See Eskeland (1994) and Eskeland and Deverajan (1996).

Various pollution control strategies analyzed in the previous section need to be examined further because the implementation of such strategies involve some costs on the part of vehicle owners and commitment of public funds on the part of the government. The latter includes initial capital outlays and operational costs involved in producing desulfurised diesel and unleaded petrol. However, a portion of these costs can be passed on to consumers by increasing the selling price of vehicle fuel. Alternatively, costs could be absorbed by the government considering the potential savings in national health expenditures. For private costs, the government has the option of using indirect measures such as tax incentives to popularize "clean car" and "clean fuel" strategies among private vehicle owners. For example, leaded and unleaded petrol are perfect substitutes and vehicle owners could be encouraged to switch to unleaded petrol by offering some fiscal incentives because the switch does not involve any additional costs by way of engine modifications.[36]

In the market, however, the price of unleaded petrol (i.e., two star petrol) can be fixed at Rs.55/liter whereas leaded petrol can be sold at Rs.50/liter. The additional cost involved in producing unleaded petrol is Rs.4/liter. Current sales of unleaded petrol are about 25,000 t per annum. Lead emission from leaded petrol in Colombo is about 60 t/annum (Annex 3). According to air quality monitoring surveys, ambient lead levels in Colombo varied from 0.001 $\mu g/m^3$ to 0.588 $\mu g/m^3$ monthly between September 1992 to August 1993. Moreover, work by Arewgoda (1994) clearly confirms the presence of high lead levels in the blood of certain target groups in Colombo. The situation may have deteriorated further over the last few years with the increase in petrol vehicles and poor traffic conditions in Colombo. It is important to note that the accumulation of lead in body organs causes anemia and damage to the kidney and central nervous system. The presence of high ambient lead levels in Colombo and the potential dangers need to be considered in designing pricing policies for unleaded petrol.

Table 13. Comparative analysis of possible cost savings due to price differential between unleaded and leaded petrol

Average petrol consumption per month	Fuel expenditure per month for leaded petrol	Possible savings per month @ Rs.48/L of unleaded petrol	Possible savings per month @ Rs.46/L of unleaded petrol	Capital recovery period for CCs @ Rs.48/L of unleaded petrol	Capital recovery period for CCs @ Rs.46/L of unleaded petrol
Liters	Rupees	Rupees	Rupees	Years	Years
80	4,000	160	320	14.0	7.0
100	5,000	200	400	11.2	5.6
120	6,000	240	480	9.4	4.7
140	7,000	280	560	8.0	4.0
160	8,000	320	640	7.0	3.5
180	9,000	360	720	6.2	3.1

CCs = catalytic converters.

[36] This is not true in the case of older vehicles manufactured before 1986. Lead in petrol is needed for these vehicles to prevent wear and tear of valve sheets (i.e., valve sheet recession) and therefore some private costs are involved.

The analysis in Table 13 attempts to examine the effect of price incentives in promoting the use of unleaded petrol with catalytic converters. It deals with two price levels for unleaded petrol, i.e., Rs.48 and Rs.46 per liter. Accordingly, potential cost savings appear to be much higher for those who consume more than 160 liters of petrol per month at Rs.46/liter of petrol. In terms of capital recovery, this price is even more attractive because it enables vehicle owners to recover the full cost of catalytic converters over a period of 3 years and 5 months.

For desulfurised diesel, the decision is rather complicated because it involves some additional costs for diesel vehicle owners and social welfare issues for the government. As noted earlier, desulfurised diesel produces 50% less sulfur dioxide. It also improves engine performance and fuel efficiency of vehicles. At present, super diesel (low sulfurised diesel) is priced at Rs.18.50/liter whereas normal vehicle diesel is priced at Rs.13.20/liter. In spite of better engine performance with the use of desulfurised diesel, majority of vehicle owners use low-quality diesel because of the lower price. Most of these diesel vehicles are relatively old and poorly tuned and hence are substantial sources of black smoke and fine particulates.

It would be interesting to examine the effect of different policy options in promoting the use of desulfurised diesel among diesel vehicle owners. First, let us consider the option of reducing the price differential between normal and super diesel. As a part of the "clean fuel" strategy, raising the price of normal diesel by 20 cents may result in an increase in tax income to the government of about Rs.209 million per annum. Based on the same assumption, if the price of normal diesel is raised by 60 and 80 cents, then the additional tax income of the government would be about Rs.418 and Rs.558 million, respectively.[37] Based on the evidence in the previous section (Equation 8), we argue that such changes may not have a significant effect on vehicle diesel consumption and hence the resulting welfare losses would be far less than the expected benefits.

In diesel fuel pricing the other policy option worth considering is the effect of reversing the existing price structure for normal and super diesel, i.e., making super diesel cheaper than normal diesel. This could be viewed as a kind of pollution tax imposed on consumers of low-quality diesel fuel. For example, the net income effect of making the price of both normal and super diesel the same (i.e., Rs.15.00/liter) and imposing a surtax of 50 cents per liter of normal diesel (i.e. Rs.15.50/liter) would be about Rs. 682 million per annum. In addition it may lead to a reduction of SO_2 by 3,115 t/annum.

High consumption of low-quality diesel has also released high levels of particulate matter in urban Colombo. Particles of 10 micron or less in diameter (PM_{10}) are especially of greater health concern because they can penetrate the tissues of the lungs. The health benefits of reducing PM_{10} in Colombo have been estimated to be about Rs.67.448 to Rs.158.782 million per annum.[38] This is an issue which deserve special attention of policy makers in fixing prices for vehicle diesel and evaluating "clean fuel" strategies.

[37] Based on 1996 vehicle diesel consumption.

[38] For details see Chandrasiri et al. (1998).

In addition to health effects, policymakers should also pay some attention on heavy dependence[39] on imported diesel because this puts the country's economic well being at risk and leads to loss of other economic benefits. Recent estimates indicated that the repair cost of a diesel car is three times higher than a similar petrol car.[40] From a national point of view extra expense on repairs of diesel vehicles means commitment of more resources for import of spare parts. In an underdeveloped economy like Sri Lanka the opportunity cost of scarce foreign reserves is much higher and therefore necessary adjustments need to be made at the policymaking level to ensure efficient use of these resources.

Except for the supply of desulfurised diesel, all other technical options discussed in an earlier section involve some additional costs for vehicle owners. For example, conversion from petrol to the dual system costs around Rs.45,000/unit. But, the economic benefits due to the price differential between petrol and vehicle gas are large enough for car owners to switch over to LPG. Table 14 shows that a vehicle owner who spends Rs.5000 on petrol could recover his capital cost within 18 months. This is reduced to 9 months for a vehicle owner who spends Rs.10,000 on petrol in a month. This example demonstrates the positive gains for LPG users without any government intervention. In fact, sales of vehicle gas has more than doubled from 9,400 t in 1996 to 25,000 t in 1997. However, the use of gas-converted vehicles is yet to be legalized in Sri Lanka. This calls for an amendment to the Motor Traffic Act. In addition, industry experts also report that the growth of the vehicle gas industry is severely constrained by the insufficient distribution network.

Table 14. Comparative analysis of monthly expenses between gas and petrol users and the capital recovery period

Fuel expenses per month	Average petrol consumption per month	Average gas consumption per month [a]	Comparative gas expenses per month	Possible savings due to use of gas	Capital recovery period
Rupees	Liters	Liters	Rupees	Rupees	Months
5,000	100	110	2,420	2,580	17.44
6,000	120	132	2,904	3,096	14.53
7,000	140	154	3,388	3,612	12.46
8,000	160	176	3,872	4,128	10.90
9,000	180	198	4,356	4,644	9.69
10,000	200	220	4,840	5,160	8.72

[a] Based on the assumption that gas consumption is 10% higher than that of petrol.

The issue of private costs in connection with catalytic converters is rather complex and the use of CC is not as attractive as that of LPG. As shown in Table 10, the use of catalytic converters results in a significant reduction in emission levels. In terms of costs, however, this involves two important elements: cost of catalytic converters (Rs.27,000 per unit) and cost of supplying unleaded petrol. The pricing policy for unleaded petrol could be viewed as an important policy option for this purpose. For example, if the price of unleaded petrol is fixed at Rs.53/liter and Rs.52/liter, then petrol vehicle owners will be

[39] At present imported diesel accounts for about 65% of total diesel consumption but was expected to go up to 75% in 1998.

[40] From a policy statement issued by the Ministry of Forestry and Environment (1998).

able to recover the full cost of installing a catalytic converter over a period of 12 and 8 years, respectively. From the government's side, potential social benefits of promoting unleaded petrol would be far greater than the loss of tax revenue, especially in the long run.

The banning of two-stroke motorcycles (2SMCs) also involves some private costs because the price differential between 2S and 4S motorcycles is about Rs.6,000 per unit. Based on current import levels this would be about Rs.51.5 million per annum. This extra cost could be treated as the welfare cost of reducing the demand for 2SMCs based on the motorcycle demand curve, which shows the price at which consumers can reduce pollution by reducing the demand for 2SMCs. It is assumed that the part of the demand curve that is above the 2SMC price shows the welfare cost of pollution reductions provided through demand reductions for 2SMCs. From an environmental effects viewpoint, less demand for 2SMCs reduces emissions by 2,418 t/annum. Hence, the introduction of some fiscal incentives on the import of 4SMCs appears to be an attractive policy option to minimize possible welfare losses due to the banning of 2SMCs.

Inspection and maintenance (I/M) and traffic management are also important strategies in controlling vehicular emissions. These two options have not been covered in the cost-effectiveness analysis due to difficulties involved in quantifying expected costs and benefits. The benefits of these strategies, however, are widely discussed in the literature.[41] Although difficult to implement, an effective I/M program can significantly reduce emission for uncontrolled vehicles. I/M programs are also needed to ensure the full benefits of "clean car" and "clean fuel" technologies. A comprehensive I/M program requires a suitable test procedure, effective enforcement of vehicle compliance, adequate attention to repair procedures and mechanic training, routine quality control, and enforcement program requirements for inspectors and mechanics. These requirements call for a properly designed program that is well-funded, politically supported, and staffed with technically competent personnel. For LDCs, special care is needed in designing I/M programs because weak administrative and regulatory arrangements could result in corruption and other problems. These could be avoided by implementing I/M programs through private contractors under the direct supervision of the government.

Lawson (1993) noted that a periodic, anticipated vehicle inspection allows vehicle owners to do whatever is expedient to pass the test, but does not encourage them to maintain emission standards. Hence, random testing of on-road vehicles, either by remote sensing or by setting up portable field testing equipment has been recognized as more effective in detecting gross emitters. Remote sensing methods monitor CO, HC, and NOx emissions of vehicles from a roadside location and they offer numerous advantages over a traditional I/M program. Remote sensing is an additional important measure of reducing emissions in combination with periodic I/M programs (Harrington and McConnell 1993). Moreover, assuming that I/M programs are well in place, remote sensing in between I/M tests improves the cost-effectiveness of I/M programs. Some researchers claim that remote sensing can replace much if not all of the mandatory I/M for identifying polluting vehicles at an average monitoring cost of only about US$ 0.50 cents per test as against roughly US$ 20 for just the test component of the enhanced I/M program.[42]

[41] For a detailed account of I/M programs see Faiz et al. (1996) and references cited therein.
[42] For details see Harrington and McConnell (1993) and references cited therein.

Traffic management policies could also make a significant contribution to pollution abatement in addition to other social benefits. This is because the impact of transport on the environment depends on the actual performance of vehicles in a given traffic situation which in turn depends on traffic management. Economic incentives and regulations which determine the traffic pattern can help significantly reduce vehicular emissions and related adverse effects on health.

7.0 SUMMARY AND POLICY RECOMMENDATIONS

The main objective of this study was to examine the effects of both technical and nontechnical (policy) issues on vehicular emissions in Colombo and to come up with cost-effective strategies for pollution control. The number of vehicles in Sri Lanka has markedly increased during the post liberalization period. Of various types of vehicles, motorcycles and dual-purpose vehicles have recorded the highest growth over the last 5 years. In composition, the relative share of diesel vehicles has increased significantly over the last 10 years. Accordingly, vehicle diesel consumption has significantly increased by 62% over the last 3 years. At present, the Ceylon Petroleum Corporation can supply only 35% of the market demand for vehicle diesel.

Existing evidence has shown that the urban environment of Colombo is contaminated with vehicular emissions. The observed Pb, TSP, SO_2, and O_3 levels are higher than the levels recommended by WHO and CEA. Petrol and diesel vehicles account for 78% and 22%, respectively of total emissions in Colombo. The low vehicle fuel price elasticity for vehicle ownership and vehicle fuel consumption suggests that the impact of vehicle fuel price through taxation changes is likely to be low. In contrast, the impact of technical measures appears to be far greater in controlling vehicular emissions in Colombo. This does not mean, however, that demand management instruments are unimportant. A package of strategies including both technical and nontechnical measures may lead to better results in controlling vehicular emissions. As noted in the previous section, phasing out of two-stroke MCs, using catalytic converters with unleaded petrol, and using LPG appear to be the most cost-effective technical options for controlling vehicular emissions in Colombo. Application of demand management instruments could further strengthen the effectiveness of technical measures for controlling vehicular emissions in Colombo.

In this context, we propose the following policy recommendations:

1. The importation of two-stroke motorcycles should be discouraged because of their considerable amount of vehicular emissions. Two-stroke motorcycles account for about 25% of total vehicular emissions in Colombo and 74% of the particulate matter among petrol-driven vehicles. Hence, banning of 2SMCs is recommended as a part of an overall strategy to control vehicular emissions in Colombo.

2. In view of expected emission reductions, the supply of unleaded petrol should be increased and its price equated with that of leaded petrol. This could be achieved with some tax incentives because both leaded and unleaded petrol are close substitutes. To realize the full benefits of using unleaded petrol, it needs to be combined with other technical measures such as introduction of catalytic converters. Adopting CCs involves some additional costs which could be reduced by making unleaded petrol less expensive compared with leaded petrol, i.e., by fixing the price of unleaded petrol at Rs.46/liter.

3. The price differential between normal diesel (Rs.13.20) and super diesel (Rs.18.20) should be reduced to control SO_2 emissions levels in Colombo. An upward price revision for normal diesel and a downward price revision for super diesel over a 5-year period are recommended. At the end of this price adjustment process we expect the selling prices of super diesel and normal diesel to be fixed at Rs.15.00/liter and Rs.15.50/liter, respectively.

4. Efforts should also be made to reduce the price differential between petrol and diesel fuel because this difference has caused an imbalanced growth in vehicle numbers in Sri Lanka.

5. The use of LPG among petrol car owners should be encouraged by maintaining the current price structure (for LPG) at least for a few more years and by providing the necessary legal support, i.e., amendment of Motor Traffic Act, setting safety standards for LPG-powered vehicles, etc.

6. In addition, transport policies such as traffic management and inspection and maintenance programs combined with the use of remote sensing should also be introduced as an integral part of vehicular emission control measures in Colombo.

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ANNEXES

Annex 1. Ambient air quality in Colombo.

Month	Station	Max. SO_2 (ppm)		Max. NO_2 (ppm)		Max. NO (ppm)		Max. O_3 (ppm)		Max. CO (ppm)	
		1hr	24hr	1hr	24hr	1hr	24hr	1hr	24hr	1hr	24hr
December '96	Peak	0.115	0.056	0.061	0.038	0.117	0.052	0.178	0.026	-	-
	Background	0.037	0.009	0.042	0.02	0.121	0.013	0.094	0.045	3.67	1.187
January '97	Peak	0.075	0.025	0.051	0.026	0.145	0.039	0.069	0.028	-	-
	Background	0.061	0.008	0.037	0.014	0.045	0.007	0.092	0.043	2.474	0.959
February '97	Peak	0.077	0.024	0.067	0.029	0.136	0.038	0.391	0.054	-	-
	Background	0.031	0.008	0.031	0.018	0.178	0.02	0.123	0.044	2.795	1.337
March '97	Peak	0.067	0.023	0.058	0.031	0.126	0.051	0.378	0.037	-	-
	Background	0.04	0.012	0.035	0.022	0.073	0.016	0.15	0.048	3.039	0.048
April '97	Peak	0.08	0.032	0.055	0.029	0.132	0.04	-	-	1.691	1
	Background	0.031	0.009	0.038	0.018	0.059	0.013	0.239	0.061	2.44	0.858
May '97	Peak	0.081	0.037	0.049	0.028	0.097	0.046	0.049	0.035	2.224	1.058
	Background	0.03	0.007	0.033	0.016	0.061	0.014	0.317	0.843	2.194	0.843
June '97	Peak	0.048	0.02	0.029	0.016	0.085	0.035	-	-	-	-
	Background	0.01	0.003	0.023	0.015	0.048	0.015	0.288	0.17	2.119	0.883
July '97	Peak	0.011	0.004	0.025	0.014	0.103	0.029	-	-	-	-
	Background	0.038	0.009	0.023	0.012	0.043	0.011	-	-	2.277	0.911
August '97	Peak	0.01	0.003	0.029	0.016	0.099	0.042	-	-	-	-
	Background	0.017	0.005	0.019	0.007	0.027	0.006	0.275	0.194	1.504	0.581
September '97	Peak	-	-	-	-	-	-	-	-	-	-
	Background	0.019	0.005	0.014	0.005	0.036	0.004	0.349	0.188	1.609	0.527
October '97	Peak	0.126	0.007	0.083	0.027	0.131	0.056	-	-	9.141	2.062
	Background	0.147	0.02	0.03	0.15	0.053	0.012	0.378	0.159	13.58	10.373
November '97	Peak	0.014	0.007	0.056	0.024	0.135	0.048	0.041	0.004	2.135	1.349
	Background	0.032	0.01	0.035	0.012	0.062	0.021	0.175	0.073	5.318	1.464
December '97	Peak	0.037	0.012	0.088	0.061	0.153	0.099	0.07	0.006	11.878	3.213
	Background	0.031	0.009	0.031	0.014	0.102	0.018	0.364	0.104	8.035	1.215

Exceed the Sri Lankan standards for ambient air quality

Source: Environmental Division, National Building Research Organization, Sri Lanka.

Annex 2. Emission factors (g/km).

	NOx	CH_4	VOC	CO	N_2O	Pb	PM	SO_2
Petrol								
Cars	2.19	0.08	4.63	49.97	0.005	0.04	0	0
Buses	6.76	0.11	5.38	58.53	0.006		0	0
Lorries	6.76	0.11	5.38	58.53	0.006		0	0
D/P	2.94	0.081	4.86	37.12	0.006		0.048	0.01
2SMCs	0.08	0.15	15.39	21.97	0.022	0.01	0.206	0.01
4SMCs	0.30	0.20	3.35	20.0	0.022	0.02	0.048	0.01
3Wheeler	0.08	0.15	15,39	21.97	0.022	0.02	0.206	0.01
Land	2.94	0.081	4.86	37.12	0.006		0	0
Diesel								
Cars	0.66	0.005	0.19	0.71	0.01	0.0	0.33	1.2
Buses	10.56	0.063	1.99	8.89	0.03	0.0	0.95	3.7
Lorries	10.56	0.063	1.99	8.89	0.03	0.0	0.95	3.7
D/P	1.43	0.005	0.42	1.57	0.017	0.0	0.37	1.7
Land	10.56	0.063	1.99	8.89	0.017	0.00	0.37	1.7

Source: OECD (1995)

Note: Emission factors for CO, N_2O and PM have been adjusted using Thai data (see Faiz et al. 1996). Emission factors for Pb is based on estimates prepared by the NBRO, Colombo

Annex 3. Estimated emission from road users in Colombo (Tons/year).

Vehicle type	Nox	CH_4	VOC	CO	N_2O	Pb	PM	SO_2
Petrol								
Cars	1,219	45	2,577	27,814	3	22	0	6
Buses	1,256	20	999	10,873	1	0	0	0
Lorries	1,544	25	1,229	13,367	1	0	0	0
D/P	537	15	888	6,783	1	11	9	2
2SMCs	89	167	17,136	24,462	2	11	229	11
4SMCs	180	120	2,008	11,991	1	12	29	6
3 Wheel	16	31	3,159	4,510	0	4	42	2
Land	17		28	211	0	0	0	0
Sub-total	4,858	423	28,024	100,012	9	60	309	27
Diesel								
Cars	81	1	23	87	1	0	40	147
Buses	4,811	29	907	4,050	14	0	433	1,686
Lorries	8,640	52	1,628	7,273	25	0	777	3,027
D/P	886	3	260	973	11	0	229	1,053
Land	245	1	72	269	3	0	63	292
Sub-total	14,662	85	2,890	12,652	54	0	1,543	6,205
G- Total	19,520	508	30,914	112,662	63	60	1,852	6,212

Note: In addition to emission factors given in Annex 2, the following data were also used in arriving at the above estimates.

Type of Vehicle	Number*	Km/y/vh
Cars - Petrol	52,462	10,610
Buses	3,440	54,000
Lorries	6,010	38,000
D/P	13,945	13,103
MCs 2 STR	149,433	7,451
MCs 4 STR	80,464	7,451
3 Wheeler - Petrol	27,548	7,451
Land Vehs - Petrol	1,792	3,177
Cars - Diesel	7,839	15,650
Buses - Diesel	8,436	54,000
Lorries - Diesel	21,530	38,000
D/P - Diesel	39,588	15,652
Land - Diesel	1,320	3,177

*Based on projected vehicle population for 1998. For details see Kumarage (1997).

Annex 4. Emission factors for petrol driven vehicles with LPG and catalytic converters (G/km).

Type of Technology	NOx	CH_4	VOC	CO	N_2O
Petrol cars with LPG	2.16	0.056	1.51	7.17	0.00
Petrol cars with Catalytic converters	0.52	0.020	0.38	2.86	0.05

Source: OECD (1995)

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